Michael P. Linegang, Michael J. Patterson, and Heather A. Stoner, Aptima, Inc.

Improving Human-Automation Interaction for Unmanned Vehicle Mission Planning

ABSTRACT

Human-automation interaction remains a key challenge for automated mission planning. Breakdowns in human-automation interaction often start with incongruence between the "optimal plan" generated by an automated planning system and the human operator's perception of sub-optimal aspects in that plan. An ecological approach to user interface design was used to generate a map of information requirements relevant to intelligence, surveillance, and reconnaissance mission planning for littoral regions. This map organized a large space of information categories relative to three mission planning purposes: 1) intelligence collection, 2) asset preservation, and 3) secrecy of the mission. Principles of ecological interface design were then used to generate a storyboard concept for presenting relevant information requirements on a display. Navy subject matter expert feedback suggests that this ecological approach holds promise for improving human-automation collaboration.

INTRODUCTION

This paper describes the design and evaluation of MiDAS (Mission Displays for Autonomous Systems), a concept for a human-automation collaboration space. MiDAS is intended to facilitate a single human mission manager in monitoring and controlling a team of unmanned vehicle systems via advanced mission planning and execution automation technologies. The objective of the MiDAS system is to improve the alignment of human mission manager and automated planning system conceptualizations of a mission. The MiDAS effort is focused on mission planning for intelligence, surveillance, and reconnaissance (ISR) missions in littoral regions. We hypothesize that improved alignment will lead to improved coordination of action between automated systems and human operators in effectively completing complex missions.

BACKGROUND

ISR is an important function performed by the US Navy. The US Navy is looking to unmanned vehicle systems (UVs) to support the ISR mission, with unmanned underwater vehicles (UUVs) playing an important role in that future mission. Transforming UVs into *force multipliers*, where a small team of human operators can manage a larger team of vehicles calls for advanced automation systems that are capable of planning and executing UV missions under the direction of the human operator. The Navy is making significant progress in developing this type of advanced automation technology (e.g. Autonomous Operations Future Naval Capability). Through these efforts, technologies are under development that can help unmanned vehicles display some intelligent behaviors (e.g., optimal task allocation based on human-specified mission goals, optimal path planning based on net-centric data, etc).

Human-automation interaction remains a key challenge for automated mission planning. Breakdowns in human-automation interaction often start with incongruence between the "optimal plan" generated by an automated planning system and the human operator's perception of sub-optimal aspects in that plan. Lessons learned from the Intelligent Autonomy Program suggest that subject matter experts sometimes question the mission plans and UV behavior produced by advanced automation systems, and have difficulties understanding how the system is generating its plans (Billman et al. 2005). These automation systems do not support effective human-automation collaboration.

Intelligent Autonomy (IA) not only requires new automation approaches; it *requires seamless integration of automated behavior with human expert decision-making*. A collaboration-space to facilitate human-automation communication and interaction in mission planning and execution is needed. MiDAS applies an *ecological approach* to improving collaboration between humans and automation. The MiDAS concept argues that the key to allowing humans and automation systems to collaborate is to establish a common *language and vocabulary* for communicating about mission plans, and then to transform that language and vocabulary into graphical relationships and graphical forms displayed in a user interface

ANALYSIS APPROACH

MiDAS's ecological approach looks to the properties of the environment as the basis for communication. ISR mission planning takes place in a complex information environment. Both human mission managers and automation systems must take action and make decisions in relation to those environmental properties, so the information properties inherent in the ISR mission environment are an ideal foundation for communication between humans and automation systems. The first step in the MiDAS project was to generate a map of the information relationships inherent in ISR mission conducted in littoral regions. This information map provides a structure for organizing the vast set of data that could potentially influence a mission plan (either from the perspective of the automation system or from the perspective of the human operator).

The Work Domain Analysis (WDA) component of the Cognitive Work Analysis (CWA) approach for systems engineering provided a useful structure for building this map. WDA is a technique that identifies the types of information that support work in a particular domain (Vicente 1999). Burns and Hajdukiewicz (2004) provide guidelines for using WDA to support the design of an ecological interface.

The MiDAS WDA identified categories of information relevant to a UV-supported littoral ISR mission. The MiDAS WDA results are described in an *abstraction hierarchy* (AH) presented in Figure 1. WDA uses a two-part hierarchical structure to organize these categories of information: 1) abstraction, and 2) decomposition. Decomposition is fairly straight-forward, with *whole system* level properties listed at the left side of an AH, and progressive *subcomponent* properties listed towards the right side of an AH. Abstraction requires a bit more discussion.

The AH organizes information categories from top to bottom according to several levels of *abstraction*. In an AH, the physical/concrete categories are grouped at the bottom level, and increasingly abstract categories are grouped towards the top. The top of the AH represents the overall purpose of the system. For dynamic systems, like an ISR mission planning system, the purpose of the system typically involves achieving a balance in tension between two or more competing purposes. As such, the MiDAS AH identifies the competing demands of "intelligence" relative to "secrecy" and "asset preservation" as the overall purposes for the system. Concrete physical objects and environmental properties are often the most easily identified categories of information, but are also vast in number. A sample of the physical objects and physical environmental properties important for IRS mission planning in littoral regions were identified (e.g. UUV's, geographic locations, time, temperature, etc.) and these physical forms are grouped at the bottom of the MiDAS WDA map. The middle layers map the functional applications of the concrete physical forms in the environment. These functions are ultimately used to achieve the highly abstract purposes of the system.

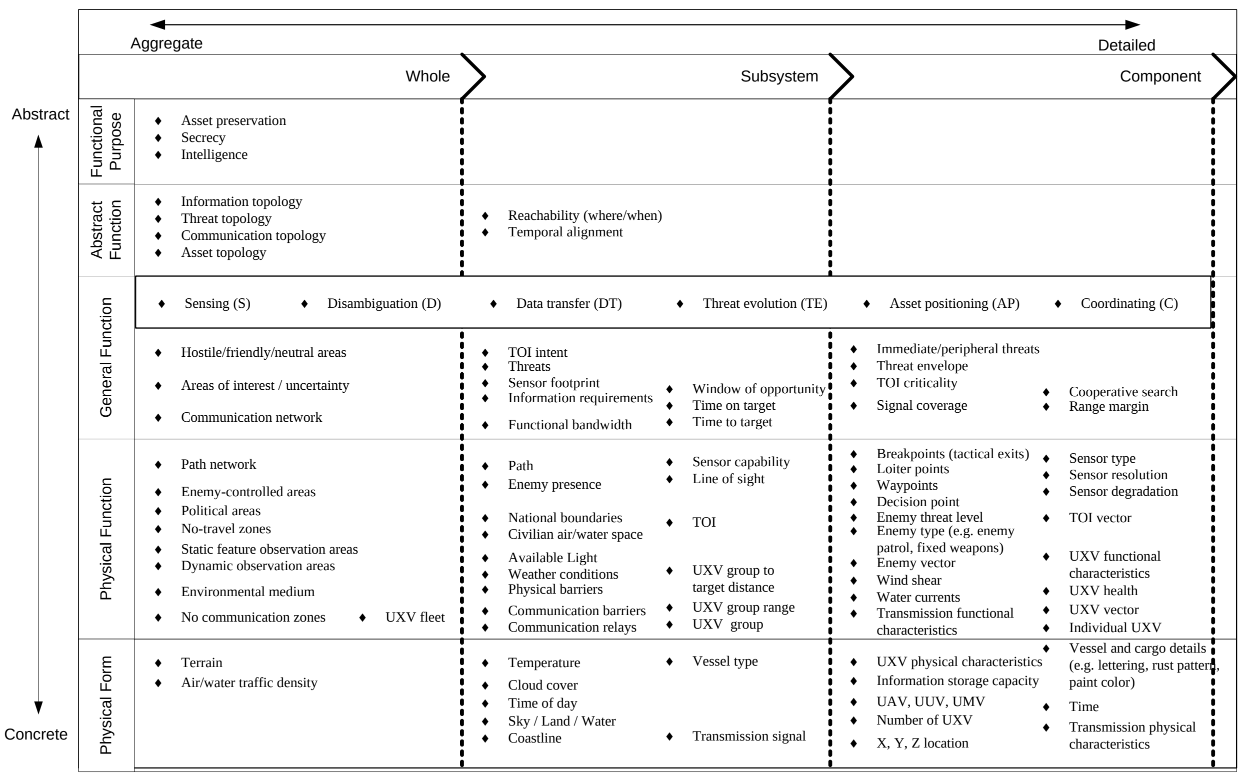

Figure 1. Abstraction hierarchy for ISR missions conducted in littoral regions using unmanned vehicles

In the MiDAS AH, information constructs that define the purpose of ISR missions are represented at the top-left portion of the AH (i.e. collect Intelligence, while maintaining Secrecy, and Preserving Assets from harm or loss). Progressively more detailed and concrete information constructs that support those purpose-level constructs are mapped into the portions of the AH proceeding to the lower right (where concrete physical characteristics of the entities and objects in the environment are described). The information constructs represented in the AH attempt to represent the types of information that might influence an automated planning system, as well as the types of information that might be relevant to the human mission manager working with that automated system. To be useful in facilitating human-automation interaction, these information requirements need to be organized into graphical forms that might facilitate shared understanding between a human operator and automated systems. The MiDAS effort produced a set of design concepts for representing the individual types of information identified in the AH, as well as the relationships between groups. These concepts were ultimately organized into a storyboard presentation which was evaluated by a focus group of Navy SME's.

DESIGN APPROACH

The initial MiDAS storyboard presented information in a geographic format. A comprehensive human-automation collaboration space for mission planning would also call for other display formats (e.g. timeline) that are not included in the initial storyboard, but planned for future design. The MiDAS storyboard is based on a scenario in which four UVs are performing a mission with enemy and neutral entities in the environment. The mission scenario requires the UVs to maintain surveillance of a primary target in an enemy port while investigating two ingress/egress routes to be used in a future manned mission.

The MiDAS design approach was based on principles of Ecological Interface Design (EID). Example principles of EID include: 1) integrate diverse information sources and support perception of whole & parts and abstract & concrete properties; 2) make relevant "invisible properties of the environment" visible on the display.

Principle #1 – Integration of Information

The MiDAS storyboard organized information from the AH for display on an interface. Abstract, high-level information constructs would be displayed during normal operations, but concrete, lower-level constructs could be accessed by decomposing display features into component parts for diagnostic purposes. Figure 2 shows two states of the MiDAS storyboard that demonstrate this principle.

Figure 2a shows a display state in which information is clustered into highly abstract, high-level groups. The "black cloud" is an abstract representation of all data within the "asset preservation" and "secrecy" groups on the AH. This feature groups together all entities that could threaten the secrecy of the mission or the safety of vehicles. For the human operator, this level of detail provides a clear distinction between "safe" and "unsafe" zones in the environment by reducing complexity. This display state would be expected to support human operators in monitor a mission during normal operations, but the abstract, high-level group would need to be decomposed in order to diagnose questionable automated plans.

Figure 2c shows the same tactical display with a state in which the asset preservation and secrecy groups have been decomposed down to more concrete, component parts. Individual enemy and neutral entity information is displayed with more detail. This display state would support operators in diagnosing specific issues with automated plans (e.g. assessing whether incursion of a potential "unsafe" zone is acceptable). However, this level of detail produces significant clutter and complexity in the display, which will likely make the human monitoring task more difficult during normal operations.

By providing operators with both display states, and an ability to toggle between the two states at relevant points in the mission, it would be predicted that a dynamic MiDAS display would support operators in monitoring a complex mission during normal operations, while still supporting diagnosis of abnormal, unexpected, or questionable plans produced by an automated system.

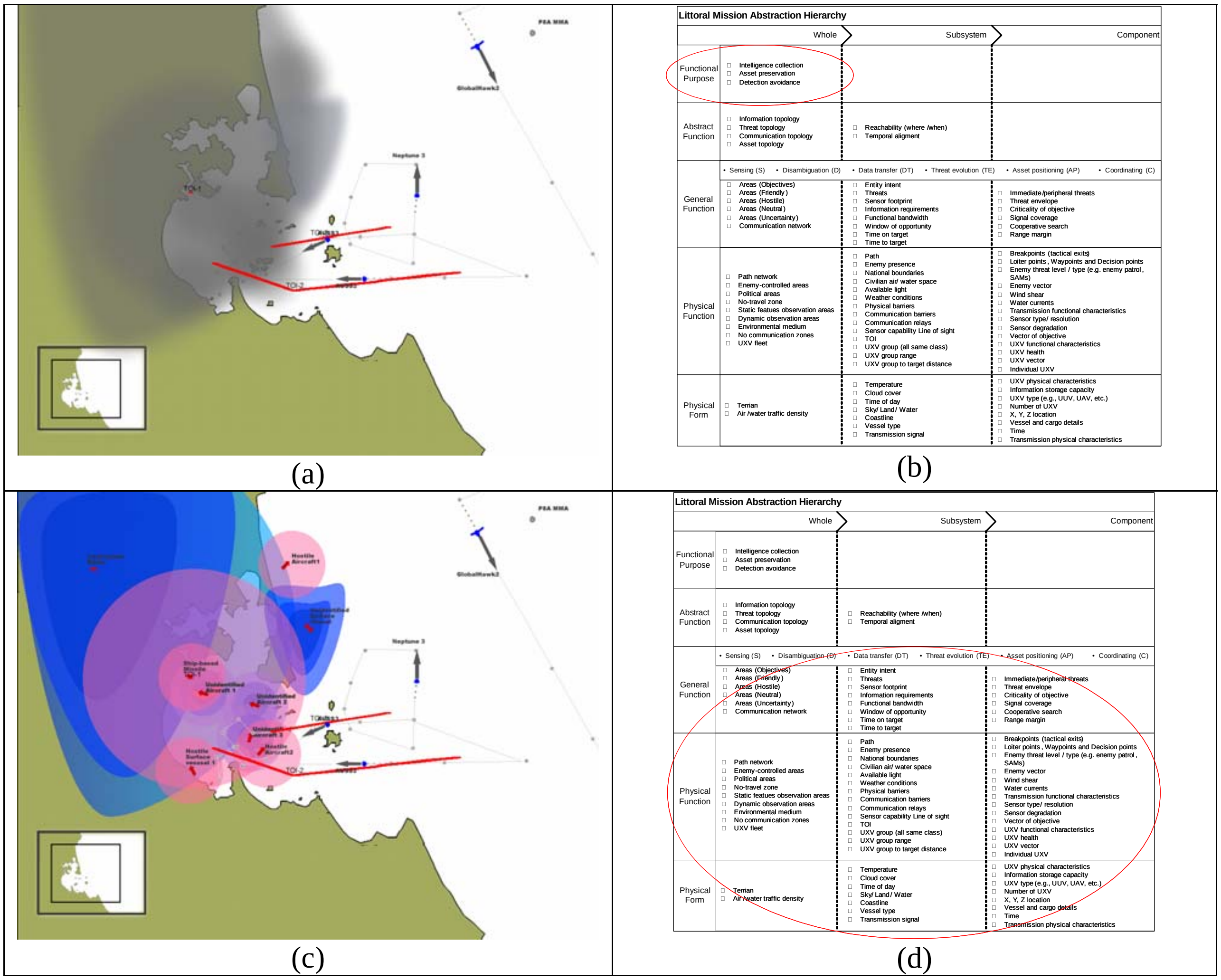

Figure 2. "High Level Abstract View" of Information Display (a) based on abstract portions of AH (b) compared to "Detailed Concrete View" of Information Display (c) based on concrete portions of AH (d) from the same point in time.

Principle #2 – Making Invisible Properties Visible

Information displays frequently transform "invisible" data to present it in a visible format on screen (e.g. temperature data presented in graphical form, etc). But emphasizing this principle of design in concert with the AH map of potential information requirements encouraged the generation of visualization concepts that could be particularly useful for supporting human-automation interaction. Figure 3 shows an example from the MiDAS storyboard that illustrates the application of this principle.

This figure suggests methods for representing several invisible constructs from the abstraction hierarchy in a manner that supports diagnosis of automated plans. The concept of *sensor footprint* is represented as a yellow shaded shape with varying levels of color saturation corresponding to the level of resolution possible for the sensor. *Threat (detection) envelope* is represented as a blue shape, with color saturation levels corresponding to the relative probability of visual detection. *Window of opportunity* is represented as a green segment along a gray planned path of travel for a vehicle. The conflict between the detection envelope and the window of opportunity is represented as a cross-hatched area, matching the color of the original path.

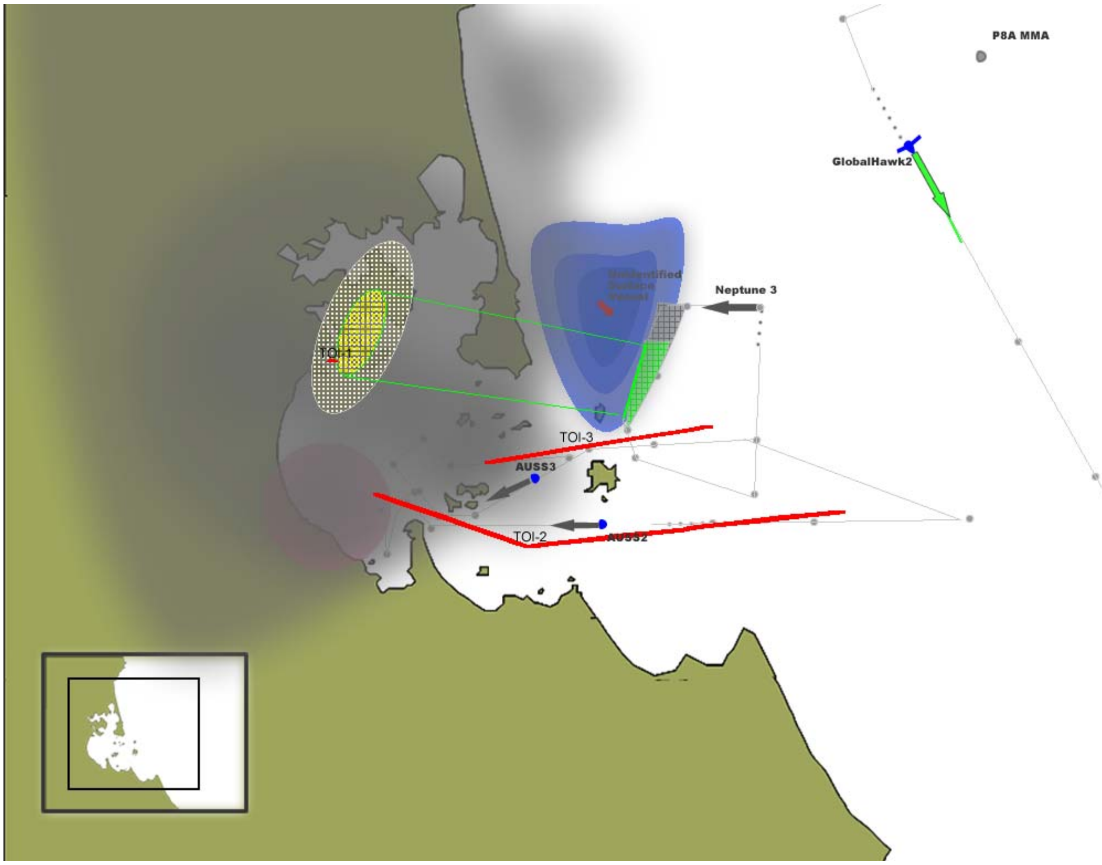

Figure 3. Visible depictions of sensor footprint, detection envelope, and window of opportunity, and the relationship between these invisible properties.

This combination of concepts provides a visual picture of a critical point in an automatically-generated mission plan, as well as a visual explanation allowing the operator to diagnose that plan. This visualization shows that the current planned path has deviated from the previous path (likely resulting from the presence of the blue detection envelope). The new green critical path places the red target of interest outside the edge of the bright yellow high sensor resolution footprint. This planned path cannot be adjusted, however, because moving the path closer to the target would move the vehicle inside the detection envelope. Visual diagnosis of this situation would allow an operator to consider alternative options for interaction with the automation (e.g. a restriction against vehicle travel within the blue detection capability region could be removed).

EVALUATION OF STORYBOARD CONCEPTS

The initial MiDAS storyboard was presented to a focus group of three experienced US Navy SME's to gather feedback about the concepts. The group included one officer (LCDR), one warrant officer (CWO2), and one enlisted (OSC), each with experience at multiple duty positions for surface vessels. This SME focus group provided valuable and constructive feedback about the MiDAS display concepts.

Principle #1 – Integration of Information

SME feedback was somewhat negative towards the concept for integration of information. We speculate that this negative feedback is largely a result of the static nature of the storyboard displays. A dynamic display, allowing the operator to quickly drill down into integrated groups of information at appropriate times, might yield more positive feedback. SME's expressed a sequence of comments that we interpreted to be very positive for the success of the MiDAS display concept once implemented in a dynamic form. When presented with a high-level view of the threat envelope (Figure 2a), SME's indicated that "unmanned vehicles are designed to go into those areas where we don't want to send manned vehicles. The question is what is considered acceptable risk?" SME's then expressed a positive reaction to the decomposition of the high-level threat envelope into its component parts (Figure 2c). This sequence of comments represented a near perfect match to the design philosophy underlying the MiDAS display. In Figure 2a, SME's indicated a clear understanding that a vehicle was projected to enter an area that could potentially pose risk to the vehicle's safety or secrecy. SME's expressed a desire at this point to be able to assess the detailed nature of the risk posed to the vehicle. Quick decomposition of the high-level display afforded the SME's the desired view that they sought for this risk assessment problem. As such, this sequence seems to indicate success for the MiDAS concept for supporting risk assessment and diagnosis. SME's also provided feedback suggesting a viable path for automated alerting in a MiDAS concept using on simple rule-based alerts. SME feedback suggests that automatic decomposition of portions of a high level display which intersect vehicle paths might be a useful capability for operators.

Principle #2 – Making Invisible Properties Visible

SME feedback was positive towards concepts for making invisible properties visible. A display mapping an intelligence collection objective to a set of overlapping sensor footprints relative to two planned vehicle paths (similar to the yellow footprint and green critical paths in Figure 3) received positive feedback. Further, the presentation of a concept display showing the intersection of a threat envelope with a planned intelligence collection path for a vehicle (similar to the blue detection capability and green cross-hatched deviations from planned path in Figure 3) received positive feedback. Overall, SME feedback seemed to validate the MiDAS concept for presentation of intelligence collection plans in a manner that supports operator understanding.

CONCLUSION

Overall, the analytical approach used in the MiDAS effort provided a mapping of information requirements as a foundation for collaboration between humans and automated planning systems. SME feedback appeared to provide support for the design approach and principles used to generate the MiDAS user interface concept. Feedback indicated a need for improvement in representation of lower level details within this user interface concept, but given that those low-level properties of the information space were not a focus in the MiDAS display design effort, that feedback certainly provides constructive direction for future work. Further, focused attention should be given to supporting quick, intuitive decomposition of high-level concepts. SME feedback pointed to the critical need to rapidly access detailed lower level information. The analysis and design approaches described in this paper appear well suited to improve collaboration between humans and automated mission planners.

REFERENCES

Billman, L., C. Cristina, D. Balmer, and N. Warner, "Multi-UxV Operator Interface: Lessons Learned and Research Gaps." Presentation given at the August 17, 2005 Intelligent Autonomy Program Review.

Burns, C. M. and J. R. Hajdukiewicz, *Ecological Interface Design*. Boca Raton, FL: CRC Press, 2004.

Vicente, K. J. *Cognitive work analysis: toward safe, productive, and healthy computer-based work*. Mahwah, N.J.; London, Lawrence Erlbaum Associates, 1999.

ACKNOWLEDGMENTS

This material is based upon work supported by the Office of Naval Research (ONR) under Contract N00014-05-M-0199. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of ONR. The MiDAS work domain analysis was led by Bobbie Seppelt, Joshua Hoffman, and Zachariah Crittendon of the University of Iowa under the direction of Dr. John Lee. Michael Polidoro, of BCI, Inc., provided US Navy operational expertise for the MiDAS effort and led the evaluation of the MiDAS storyboard.

Michael P. Linegang *is the principal author and principal investigator for the MiDAS project. He is the Leader of the Systems Engineering and Evaluation Team at Aptima, Inc. Mr. Linegang's research interests include the application of Cognitive Work Analysis techniques to the design of command and control decision support systems and intelligence analysis tools, and the use of modeling, simulation, and field data collection techniques in evaluating the effects of intelligent systems. He holds a master of education degree from The Ohio State University and is nearing completion of a master of arts in experimental psychology/human factors from the University of Dayton.*

Dr. Michael J. Patterson *led the task of designing the MiDAS user interface concepts. He is the Leader of the User Experience Team at Aptima, Inc. Dr. Patterson has over 20 years of experience in the application of human factors and user centered design principles to interactive systems development. His expertise includes the analysis, design, and usability evaluation of software product user interfaces to provide novel means of product interaction across a variety of industries. He holds a Ph.D. and M.S. in engineering psychology from the Georgia Institute of Technology.*

Heather A. Stoner *was a primary contributor to the creation of ecological representations of information and creation of the MiDAS abstraction hierarchy. She is a Human Systems Analyst at Aptima, Inc. Ms. Stoner has interests in the application of Cognitive Work Analysis and Ecological Interface Design to the development of novel systems within military and transportation domains. Specifically, she uses these methodologies to drive the evaluation of system design effectiveness and the assessment of real-world implications. She obtained her master of science in industrial engineering at the University of Iowa.*